Brain and Cognition 123 (2018) 10–22

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Non-invasive brain stimulation to investigate language production in healthy speakers: A meta-analysis

Jana Klaus*, Dennis J.L.G. Schutter

Radboud University Nijmegen, The Netherlands

ARTICLE INFO

Keywords:
Language production
Meta-analysis
Picture naming
Verbal fluency
TMS
tDCS

ABSTRACT

Non-invasive brain stimulation (NIBS) has become a common method to study the interrelations between the brain and language functioning. This meta-analysis examined the efficacy of transcranial magnetic stimulation (TMS) and direct current stimulation (tDCS) in the study of language production in healthy volunteers. Forty-five effect sizes from 30 studies which investigated the effects of NIBS on picture naming or verbal fluency in healthy participants were meta-analysed. Further sub-analyses investigated potential influences of stimulation type, control, target site, task, online vs. offline application, and current density of the target electrode. Random effects modelling showed a small, but reliable effect of NIBS on language production. Subsequent analyses indicated larger weighted mean effect sizes for TMS as compared to tDCS studies. No statistical differences for the other sub-analyses were observed. We conclude that NIBS is a useful method for neuroscientific studies on language production in healthy volunteers.

1. Introduction

Transcranial magnetic (TMS) and direct current stimulation (tDCS) are non-invasive brain stimulation (NIBS) techniques that are increasingly used to investigate causal relationships between language functions and their underlying neuronal processes. The aim of this combined review and meta-analysis is to examine the efficacy and reliability of NIBS as an intervention method to study the neural correlates of language production in healthy volunteers. Prior meta-analyses on the effects of transcranial direct current stimulation (tDCS) on verbal fluency and picture naming have provided diverging results. Both Horvath, Forte, and Carter (2015) and Price, McAdams, Grossman, and Hamilton (2015) analysed performance changes in semantic production and word learning tasks, with the first finding no effect, but the latter reporting a reliable modulation of task performance. Furthermore, Westwood and Romani (2017) found no effect of tDCS on language production performance across production and reading tasks. Our present review offers an overview and meta-analysis of studies which measured changes in verbal fluency and picture-naming performance during or following the administration of tDCS or transcranial magnetic stimulation (TMS). Furthermore, by differentiating between different experimental parameters, we aim to provide a more detailed picture with respect to the usefulness of NIBS studies that investigate language production in healthy volunteers.

Picture naming (i.e., the production of a noun or verb in response to a visually presented stimulus) is the most direct way to measure language production performance. Cortical activity during this task has been located in a large left frontotemporal network stretching from interior frontal to posterior superior temporal and inferior parietal regions (Indefrey, 2011; Indefrey & Levelt, 2004). Using TMS, which applies an ultra-short electromagnetic pulse that creates an electric current in superficial cortical nerve tissue, an engagement of the posterior superior temporal gyrus (pSTG), middle temporal gyrus (MTG), anterior temporal lobe (ATL), and inferior frontal gyrus (IFG) has been demonstrated (Acheson, Hamidi, Binder, & Postle, 2011; Mottaghy et al., 1999; Pobric, Jefferies, & Lambon Ralph, 2007, 2010; Schuhmann, Schiller, Goebel, & Sack, 2009, 2012; Shinshi et al., 2015; Sparing et al., 2001; Töpper, Mottaghy, Brügmann, Noth, & Huber, 1998; Wheat et al., 2013). Furthermore, cortical excitability can be modulated by applying a constant weak electric current between two electrodes affixed on the scalp. Although the vast majority of the electric field is shunted, a small yet significant portion of the field reaches the superficial layers of the cortex (Nitsche et al., 2008). Research on the human motor cortex has shown that anodal tDCS increases spontaneous neural firing and cortical excitability, while cathodal tDCS reduced spontaneous neural firing and lowered cortical excitability (Nitsche & Paulus, 2000; Stagg & Nitsche, 2011). Its potential to modulate underlying cortical tissue together with the facts that tDCS is not associated with serious adverse advents and allows for better (double) blinding procedures as compared to TMS has

* Corresponding author at: Radboud University Nijmegen, Donders Centre for Brain, Cognition and Behaviour, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands.
E-mail address: j.klaus@donders.ru.nl (J. Klaus).

https://doi.org/10.1016/j.bandc.2018.02.007
Received 8 November 2017; Received in revised form 1 February 2018; Accepted 13 February 2018

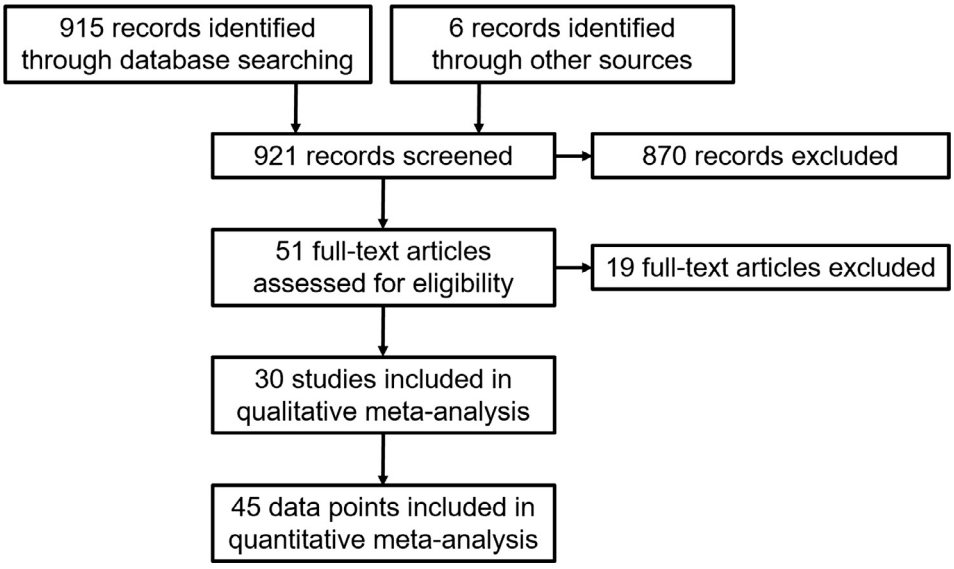

Fig. 1. Flowchart of literature search for the meta-analysis.

contributed to its increased use in cognitive neuroscience. Indeed, a number of studies have reported significant effects from applying anodal tDCS over the left STG and dorsolateral prefrontal cortex (DLPFC) on object and action naming (Fertonani, Brambilla, Cotelli, & Miniussi, 2014; Fertonani, Rosini, Cotelli, Rossini, & Miniussi, 2010; Sparing, Dafotakis, Meister, Thirugnanasambandam, & Fink, 2008). Interestingly, NIBS typically only affects naming latencies, but not error rates, in picture naming tasks.

Next to the classic picture naming tasks, a number of studies have also investigated the effects of tDCS and TMS on naming latencies in the semantic blocking and picture-word interference paradigm. In semantic blocking tasks, naming latencies are compared between semantically homogeneous (i.e., containing words from the same semantic category) and heterogeneous blocks (i.e., semantically unrelated words). Retrieving and producing semantically related words in a row typically results in longer naming latencies compared to producing semantically unrelated words. This semantic interference (SI) effect is taken as evidence for competitive selection of target responses (e.g., Belke, Meyer, & Damian, 2005; Damian, Vigliocco, & Levelt, 2001; Kroll & Stewart, 1994) and has been localised predominantly in the left temporal cortex (de Zubicaray, Johnson, Howard, & McMahon, 2014; Indefrey, 2011). Confirming this, studies applying tDCS (Meinzer, Yetim, McMahon, & de Zubicaray, 2016; Pisoni, Papagno, & Cattaneo, 2012) or TMS (Krieger-Redwood & Jefferies, 2014) before or during semantic blocking tasks reported an involvement of pSTG, but not IFG. These studies provide first evidence that processes involving lexical selection and retrieval can be targeted using NIBS. However, it should be kept in mind that behavioural effects were numerically small (see also Westwood, Olson, Miall, Nappo, & Romani, 2017, Experiment 2, for statistical null effects of tDCS across the left IFG in a semantic blocking task).

The picture-word interference (PWI) paradigm allows for the chronometric investigation of speech production processes on the timescale of tens of milliseconds (e.g., Damian & Martin, 1999; Schriefers, Meyer, & Levelt, 1990). Participants are asked to name pictures while ignoring a visually or auditorily presented distractor word, the relatedness of which to the target word is systematically varied. Typically, a semantically related distractor (e.g., *"cow"* when the target word is *"sheep"*) increases naming latencies compared to an unrelated distractor, while a phonologically related distractor (e.g., *"sheet"*) speeds up naming latencies. Varying the onset of the distractor relative to picture presentation (stimulus-onset asynchrony, SOA) enables researchers to examine the time course of speech planning with respect to the individual representational levels involved. Recall that lexical-semantic processing has been associated with the left MTG, while phonological processing has been located in the left STG (Indefrey, 2011; Indefrey & Levelt, 2004). In line with this, Henseler, Mädebach, Kotz, and Jescheniak (2014) reported a decrease of associative facilitation (i.e., when the distractor is associatively related vs. unrelated to the target word, e.g. *"boat"* and *"port"*) under MTG as opposed to IFG and sham stimulation (anodal tDCS). Furthermore, Pisoni, Cerciello, Cattaneo, and Papagno (2017) found reduced phonological facilitation following anodal tDCS to the STG, but no such effect when IFG was stimulated.

Finally, a number of studies also measured performance changes in response to TMS or tDCS in verbal fluency tasks (see also Horvath et al., 2015; Price et al., 2015). In these tasks, participants are asked to produce as many words as possible from a given semantic category (i.e., semantic fluency) or starting with a given letter (i.e., letter fluency) within a time constraint. High fluency scores reflect unimpaired speech production on the semantic or phonological level, respectively. Neuroimaging evidence has shown that both tasks involve left frontal, temporal, and parietal regions, with dissociable activity in the MTG in the semantic and in the IFG in the letter fluency task (Birn et al., 2010). Previous studies investigating the effect of tDCS on verbal fluency have provided ambiguous results. While some studies report increased verbal fluency during or after tDCS (IFG: Cattaneo, Pisoni, & Papagno, 2011; Iyer et al., 2005; Penolazzi, Pastore, & Mondini, 2013; Pisoni, Mattavelli, et al., 2017; DLPFC: Vannorsdall et al., 2012), others did not obtain such an effect (IFG: Ehlis, Haeussinger, Gastel, Fallgatter, & Plewnia, 2016; Vannorsdall et al., 2016; DLPFC: Cerruti & Schlaug, 2009).

To date, there are still many unknowns about the influence of different stimulation parameters on the behavioural (language production) effect induced by NIBS. In order to quantify the overall effect of NIBS observed across studies and to examine individual subsets contrasting different experimental parameters, we performed a meta-analysis evaluating the behavioural performance changes during language production tasks in healthy participants. With respect to language production, rather small effect sizes of tDCS treatment for clinically relevant populations (Hartwigsen & Siebner, 2013) raise the question whether this method is a useful tool in altering language production in healthy speakers, and previous meta-analyses are inconclusive (Horvath et al., 2015; Price et al., 2015; Westwood & Romani, 2017), as they analysed fewer studies and used diverging methods. Here, unlike these previous studies, we investigated the absolute effect sizes